A Multiagent Approach for Modelling SME Mechatronic Supply Chains

Jihène Tounsi, Selma Azaiez, Georges Habchi, Julien Boissiere

A multiagent approach for modelling SMEs mechatronic supply chains

J. Tounsi, S. Azaiez*, G. Habchi, J. Boissière

Université de Savoie, Annecy le vieux, 74940 France
(email:{ jihene.tounsi ; georges.habchi ; julien.boissiere}@univ-savoie.fr)

**CEA, LIST*
Embedded Real-Time System Foundations Laboratory
Mail Box 94 - F91191 Gif sur Yvette Cedex, France
(email:selma.azaiez@cea.fr)

Abstract: This paper presents the application of the multiagent system for modelling supply chains involving Small and Medium Enterprises (SMEs) in the mechatronic industry. This work is a combination of two research scopes. The first one deals with the identification of the different concepts able to model the particular manufacturing systems and production context in Savoie – France. The second one outlines the development process based on an agent modelling approach, which offers an easy and reusable modelling of supply chain concepts.

Keywords: SME, supply chain, multiagent, modelling, simulation

1. INTRODUCTION

The supply chain concept was born in the 90s when management techniques in the business world evolved from separate logistics to collaborated logistics. It is well known that the supply chain is a complex macro system; firstly, this complexity is due to the variety of the implicated organisations and diversity of relationships between them, and secondly it results from the decision-making mechanism between these companies. Thereby, the success and subsistence of a company in the economic market lie in its ability to integrate the managerial processes but also to coordinate with other actors (Drucker, 1998; Lambert and Cooper, 2000). In this context, SMEs evolve in an unstable and complex network. In order to guarantee its role in a supply chain, a SME must be able to support the inherent requirements of the chain (delays, consumer satisfaction, etc.) and the external requirements due to the environment (unpredictable mutation, competition, etc.). Consequently, SMEs have to collaborate together in order to achieve their goals without losing their autonomy and identity (Villarreal *et al*., 2005; Julien, 1997).

The industrial environment of the Savoie region in France is mostly composed of SMEs manufacturers or subcontractors in the mechatronics field. These SMEs are clustered into networks in order to achieve a common goal in a complex global supply chain. Indeed, according to some investigations and studies on the environment, three major features of the supply chain which integrates SME clusters and especially mechatronic ones arose (Tounsi *et al*., 2008). Firstly, supply chain in this context is a complex system. This complexity is due to the high number of autonomous actors and SME networks which collaborate to achieve a given process. Secondly, the studied SMEs are not necessarily located in the same geographical area as the other nodes of the supply chain. And finally, as a result of the two previous characteristics, SMEs face a lack of visibility in the global supply chain. Then, the studied supply chain is divided into many sites spread over several geographic locations depending on their purpose or activity in the global supply chain. These sites only have a local visibility but are coordinated with other sites through the product flows. For all these reasons, studying the structure and the behaviour of the supply chain in SMEs mechatronics field has became a challenge and a growing need was expressed by the producers in the Savoie.

In order to meet this need, this paper proposes a modelling approach based on a development process that aims at identifying and modelling the domain concepts. This modelling approach is based on using different layers that represent different views of the system (the system refers to a supply chain). Representing the domain concepts within models allows capitalizing the know-how and then facilitates the supply chain concepts reuse within different contexts.

The paper is organised in four major sections. The first section presents some existing supply chain modelling approaches and focuses on the multiagent modelling one. Also, the motivations for the agent paradigm to model the supply chain are clarified. In the second section, the ArchMDE (Architecture Model Driven Engineering) development process is introduced and its contribution to this research is detailed. Finally, the two last sections, present the different steps to generate the conceptual metamodel and its agentification according to the described development process.

2. LITERATURE REVIEW

2.1 Supply chain modelling approaches

Labarthe *et al*. (Labarthe *et al*., 2007) distinguish three main types of approaches for supply chain modelling: organizational, analytical and simulation.

The organizational approaches rely on process modelling based on the systems theory. The models of the supply chain generated by the use of these approaches are usually not able to evaluate the dynamic behaviour of the system over time when facing stochastic environmental stimuli.

The analytical approaches rely on mathematical formalizations of the chain. The obtained models are simplified, require usually restrictive assumptions, and are limited in taking time into account. Two such approaches are the control theory approach based on differential equations, and the operational research approach, which relies on optimization theories.

Supply chain modelling and simulation (M&S) is based on system dynamics and on the behaviour of different autonomous entities. It is subdivided into two different scientific research ways: continuous simulation and discrete event simulation. Currently discrete event simulation is the preferred mainstream (Terzi and Cavalieri, 2004).

Modelling is a mechanism that reflects the actual system and provides a very powerful decision-making tool when coupled to simulation. The literature is unanimous on the positive role of M&S in complex systems study, analysis and performance evaluation. For example, some authors (Lee *et al.*, 2002; Longo and Mirabelli, 2008; Ingalls, 1998) highlight the features and advantages of a decision-making tool based on modelling and discrete event simulation.

The M&S approach was adopted in several works in order to reduce the complexity of the supply chain and evaluate its performance (Bagchi *et al.*, 1998; Labarthe *et al.*, 2007). M&S translates the conceptual model of the supply chain and recreates the complexity and highly stochastic environment of an actual system. The conceptual model defines concepts (implicated entities) and parameters that give the possibility to a supply chain manager to analyze different scenarios by changing input parameters (Longo and Mirabelli, 2008).

In supply chain M&S there are two main types of modelling: the equation-based modelling and the agent-based modelling. Parunak *et al.* (Parunak *et al.*, 1998) have proved that multiagent systems and agents are more suitable to model the dynamics behaviour of the complex network of manufacturing system and to study the impact of flow coordination between different entities than the equation-based modelling.

In this work we have chosen to adopt the multiagent system to model and simulate the supply chain in the SME context. The motivations for this choice are highlighted in the next sub section.

2.2 Agent-based modelling of the supply chain

Multiagent system is a new M&S paradigm of complex systems. Multiagent approach is born from the combination of two research ways: “artificial intelligence” and “object-oriented modelling”. Demazeau (Demazeau, 1996) defined the multiagent system as a set of four main views named “Vowel approach” or “AEIO approach”:

- Agent view (A): describes the internal structure of an agent. An agent is a computer system able to act autonomously in a given environment in order to meet design objectives (Wooldridge, 2002). The scientific community distinguishes three kinds of agent according to their decision-making model and intelligence degree. (i) The reactive agents that react to changes through predefined actions (Brooks, 1991). (ii) The cognitive agents having a reasoning faculty and the ability to choose the adequate action in order to achieve optimally a specific goal. This kind of agent also has a learning faculty enabling it to evolve in a decision-making system such as BDI agent ((Wooldridge, 1999), (Bratman et al., 1998)). (iii) The hybrid agent, which is a crossover between the reactive agent and the cognitive agent (Fischer et al., 1995).
- Environment view (E): describes the environment in which an agent evolves. FIPA (Federation of Intelligent Physical Agents) specification defined it as “...all that is external to the agent”. According to Azaiez et al. (Azaiez et al., 2007), the environment view can define two different kinds of environment: the simulated one and the deployed one. The simulated environment is a computer representation of an actual environment. It is generally modelled by a metric. The deployed environment deals with computers and appliances in which agents can be deployed, as well as resources that the agent can use. In the context of deployed environments, resources correspond to databases, indicators, variables, etc.
- Interaction view (I): describes the dynamic relationships between agents through protocols or interaction language. This interaction is a structured exchange of messages according to the internal state of the agent and the kind of the interaction framework (coordination, collaboration, cooperation or negotiation).
- Organization view (O): describes the structure of the whole system in terms of agent groups, hierarchy, relationship and the structure of the other entities which constitute the environment.

The AEIO approach decomposes the whole multiagent system in several modules. This modularity facilitates the reuse of the different modules according to the requirements. In addition to this modularity, agents are more suitable for applications that are decentralized, changeable, ill-structured (dynamic structure) and complex (Parunak, 1998). So, the multiagent approach provides a framework naturally oriented to model the supply chain. By comparing the supply chain and the multiagent system characteristics, similar concepts and the same organizational practices arise. In fact, both are composed by actors or entities which evolve in an organization and interact to achieve a collective purpose. This analogy leads to multiagent approach being a privileged way to model the supply chain system.

3. ArchMDE DEVELOPMENT PROCESS

In this paper, the goal is to combine multiagent concepts and supply chain ones in order to build an agentified conceptual model for supply chain in SMEs context. To reach this purpose, the modelling approach recently proposed within a PhD research work (Azaiez, 2007) is used. This approach is based on the Model-Driven Engineering (MDE) (Kent, 2002) which roots developing process on producing several interrelated models. MDE promoted the separation and combination of concerns in software engineering. Applying this approach allows to control the software development process in its different phases (from the analysis until the implementation).

One of the most important issues in MDE approach is the metamodelling one. A metamodel targets important aspects of software. It defines domain concepts, their relationships and their properties. In MDE approach, metamodels are not only descriptive models. They are the core of the development. All models produced in the different development phases (from the analysis until the implementation) have to conform to the metamodel.

In ArchMDE approach, two types of metamodels are identified: a domain metamodel that describes functional concepts and properties related to a particular domain (i.e. a SME supply chain) and a computer modelling metamodel (i.e. a multiagent system). A combination of both metamodels will generate an agentified metamodel, that constitutes the starting point of conceptual models. From this last metamodel, different functional models are described in order to introduce the functionalities of the system (Fig 1). Finally, the use of a platform metamodel is necessary to generate the program code.

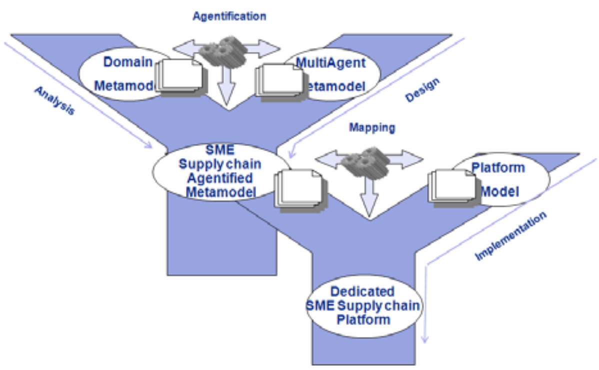

Fig 1. ArchMDE development process.

This approach is of great interest to fill in the existing gap between the design and the implementation phases. In this paper, we focus on the first phase of ArchMDE development process. The following section introduces the conceptual domain metamodel and its agentification.

4. CONCEPTUAL DOMAIN METAMODEL

According to the ArchMDE development process, the first modelling step involves the definition of the conceptual model. This step leads to the identification of the main concepts of SME mechatronic supply chain. To achieve this objective, we follow a methodology based on existing conceptual modelling visions in the literature (Tounsi *et al.*, 2008). In this methodology, the visions are organised in three steps. Each step addresses the concepts related to supply chain. These concepts and their relationships will then be gathered within a domain metamodel that will be expressed using UML (a semiformal Unified Modelling Language). The following section presents this methodology.

4.1 Conceptual modelling methodology

To identify the properties and concepts of the supply chain domain, an incremental methodology combining three visions is proposed: product vision, structure vision and process vision. In each step, a vision is applied to build or to refine the conceptual model. The result of each step (intermediary model) is the input of the next one. Therefore, at the end of the 3 steps, a final architecture of the conceptual model is generated (Fig 2).

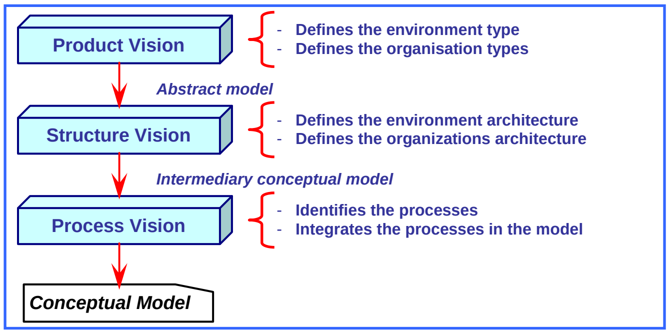

Fig 2. Conceptual Modelling Methodology Framework (Tounsi *et al.*, 2008)

Step 1: Product Vision

This vision considers the supply chain dedicated to a particular product (or a family of products) from the raw materials to the final goods. It focuses on the product flow to define the environment and organizations implicated in its management (Thierry, 2003). In the methodology framework, *Product Vision* leads to the construction of a first abstract model of the supply chain involving environment and organizations:

- The environment is characterized by the flow circulation and the different steps of the product transformation as well as related disturbances.
- The organizations are the entities carrying out one or several stages of product transformation and the physical flow management. In the studied context, the supply chain is essentially composed of SMEs. The implicated organizations can be a network of firms that collaborate to accomplish one or several stages of transformation.

Step 2: Structure Vision

This vision has been proposed by Cooper *et al.* (Cooper *et al.*, 1997). It considers the architecture of the supply chain made of: actors (decision-making actors and synchronization actors), network structure (roles in the network and the number of actors in each role) and relationship characteristics between actors. So, on the basis of the abstract model provided by the previous step, *Structure Vision* details the involved organizations and the physical environment:

- The environment is the part containing the physical flow. Therefore, the product flow and the resources used to achieve its transformation have to be described.

- The organization consists in identifying and prioritizing the actors in the network according to their involvement in decision-making level as well as the tasks that will be awarded. The information flow management depends on the decision-making level.

At this step, a more detailed intermediate model is built.

Step 3: Process Vision

This vision is based on processes classification according to the decision-making level (Chopra and Meindl, 2001; Stevens, 1989): strategic, tactical and operational.

While applying "Process Vision", various categories of processes are identified and integrated to the previous intermediate model. This can be done according to decision level but also depending on the actors' relationships. These relationships can be classified in two categories:

- Management and control: contain processes that ensure suitable decision implementation in the perspective of a continuous improvement of processes in terms of added value.

- Synchronization: contains processes for exchanging information and physical flows according to a process scheme developed and already predefined by the decision-making layers.

This step leads to a refined conceptual model of the supply chain.

4.2 Domain model concepts

This section presents the concepts that constitute the domain model. By applying the methodology, several concepts, architecture and processes of the model were identified. Based on these concepts, a metamodel of supply chain is proposed.

Step 1: Applying Product Vision

By applying *Product Vision*, a first abstract model of the supply chain is built. It is composed of (Fig 3):

- Environment: the space allocated to the product flow and management through the internal resources as well as the external elements able to influence supply chain activities.

- Sub Supply Chain (SSC) represents a group of SMEs which collaborate to achieve an internal aim and/or the overall objective of the supply chain. The SSC is responsible for the managing of the product flow in a certain stage of its life cycle.

- Perimeter of influence: represents the visible part of the environment to the SSC on which it can act by internal conferring (if the action does not disturb the environment located at the outside of its visibility) or by conferring with other SSC.

- Shared perimeter of influence: represents the area of the flow transfer between two SSC. It is a shared zone where SSC coordinate their activities to allow the flow transfer.

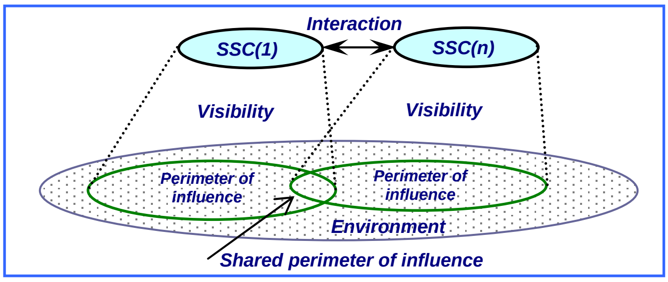

Fig 3. The Abstract Model (Tounsi *et al*., 2008)

Fig 4 shows the domain metamodel which reflects this conceptual abstract model using UML notation.

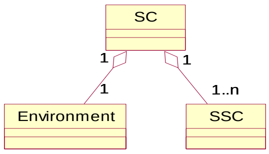

Fig 4. Abstract Domain Metamodel

Step 2: Applying Structure Vision

By applying *Structure Vision*, the previous abstract model is refined. The internal architecture of the SSC and the visible part of the environment (the perimeter of influence) are described. As showed in Fig 5, the SSC model and its environment are based on three layers representing the different decision-making levels (Fig 5).

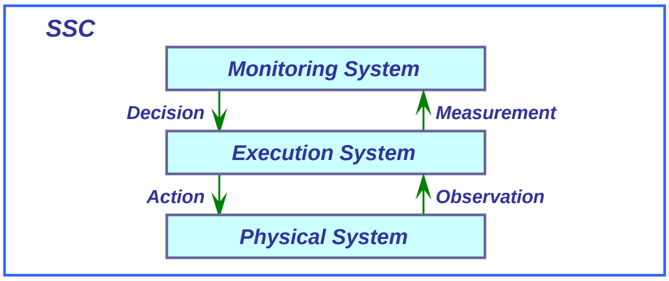

Fig 5. Layers of the SSC (Tounsi *et al*., 2008)

Each layer involves particular concepts and plays a specific role in the SSC:

- The *Monitoring System* is the intelligent layer of the SSC. It controls and monitors the two other layers through the information provided by the Execution System. Monitoring Actors (MAs) that model the intelligent actors of SSC are the main elements of this layer. They establish metrics to evaluate the performance of the group and consequently act on the two other layers. Hence, MAs are the components in charge of controlling and decision-making in the SSC as well as coordinating activities of the global supply chain.

- The *Execution System* is the reactive layer of the SSC. It deals with two main roles: (i) it ensures the synchronization of the physical flow according to the information gathered from the *Physical System*, (ii) it observes and corrects the *Physical System* if a perturbation already occurred. In abnormal situations, the Execution System refers to the *Monitoring System* for coordination and decision-making. Executive Actors

(EAs) are the principal entities of this layer. An EA mainly models the reactive actor and occasionally MA with reactive behaviour in this layer.

- The *Physical System* is the visible part of the SSC environment. It corresponds to the perimeter of influence of the SSC. This layer is composed of passive elements controlled by the two other layers of the SSC. Two main concepts are identified: the Moving Entity (ME) modelling the product in circulation and the Resource modelling production means.

Fig 6 shows the first conceptual abstract model refined in a domain metamodel.

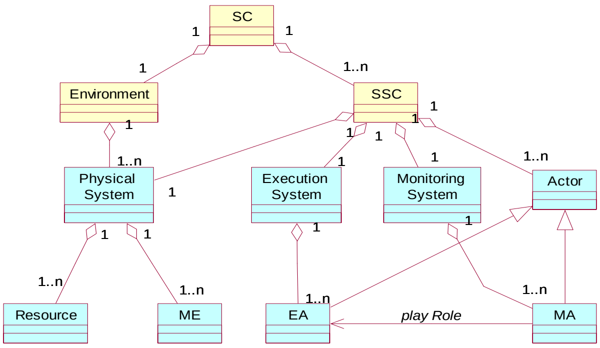

Fig 6. Intermediary Domain Metamodel

Step 3: Applying Process Vision

The object of the last step is to identify and integrate the different kinds of processes in the model. Table 1 gives a classification of the identified processes according to their role in decision-making. In the *Physical System*, the Physical Processes (PhPs) have been identified. A PhP describes the sequences of processing stages of the product. It is a concept to be integrated within a domain metamodel in order to define the tasks that can be handled by the *Execution System*.

Table 1. Process Classification

SSC Layer	Process Family	Role
Monitoring System	Strategic Processes (SPs)	- Coordinate decision in the long term
	Monitoring and Control Processes (MCPs)	- Monitor SSC activities - Drive and evaluate SSC performance in the global supply chain
Execution System	Operational Control Processes (OCPs)	- Synchronize and control the physical system
Physical System	Physical Processes (PhPs)	- Define the transformation routings of products

The processes identified in both *Monitoring* and *Execution Systems* are management processes. Hence, they represent the dynamic behaviour of the SSC. This behaviour is induced by control and monitoring decisions that come from either the SSC or the global supply chain. It uses a communication mechanism (coordination, collaboration or cooperation).

In order to model management processes and communication mechanisms, more details are needed for EAs and MAs to ensure their role in the domain model. As EAs are reactive actors, they support Operational Control Processes, based on two conceptual elements that consolidate the EA architecture:

- Indicator Base: represents a database storing indicator measures. The EA detects *Physical System* deviation according to the gathered information within this database.
- Action Base: represents a database that stores actions to apply when facing indicator deviation.
- In the same way, the intelligent behaviour of the MA requires the definition of other conceptual components:
- Objective: models the strategic goal of the SSC. According to this aim, the SSC coordinates its activities with other SSCs of the global supply chain.
- Knowledge base: represents a database including all knowledge needed by the actor to make the right decision. This knowledge can be an organizational knowledge or a constraint.
- Organisational Knowledge: is an actor's database that stores information about his acquaintances.
- Constraint: is a variable that an actor must consider to reach the global supply chain goal or the SSC's one.

Through the *Process Vision*, the previous metamodel and its concepts are refined. The choice has been done to model "Indicator base" and "Action Base" as shared databases between all actors of the same SSC. In the same way, the concept "Objective" models shared SSC goals accomplished by MAs. Figure 7 presents an UML representation of the final domain metamodel for the supply chain in SMEs context. It corresponds to the final conceptual model with its associated concepts regardless of any computer technology.

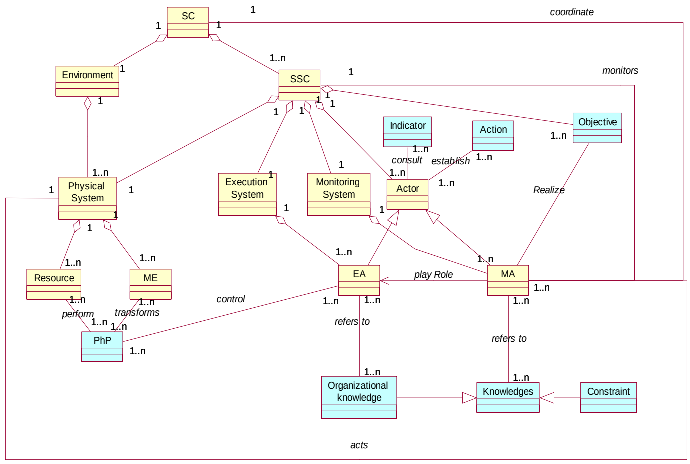

Fig 7. Global Domain Metamodel

5. AGENTIFIED SME SUPPLY CHAIN METAMODEL

In this section, the domain metamodel is merged with an agent metamodel according to the ArchMDE methodology (Azaiez, 2007). This combination provides an agentified SME supply chain metamodel. On the one hand an agent metamodel models multi-agent system with all agent concepts modelled according to the “vowel approach” (Fig 8). On the other hand a domain metamodel describes the supply chain in SMEs mechatronic context (Fig 7). A correspondence between the multi-agent concepts and the domain ones is then carried out according to their properties and their roles in the metamodel. Table 2 summarises the correspondence between concepts in order to obtain the final agentified metamodel for SMEs mechatronic supply chain.

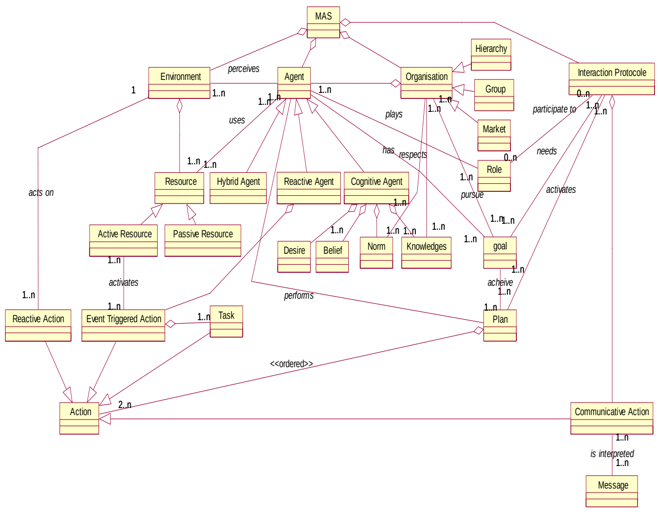

Fig 8. Agent Metamodel (Azaiez, 2007)

Table 2 Correspondence between Domain and Multiagent concepts

Domain concepts	Multiagent concepts
Supply Chain (SC)	MAS
Environment	Environment
Physical System	Resource
Resource	Passive Resource
Moving Entity (ME)	Active Resource
Physical Process (PhP)	Task
Sub Supply Chain (SSC)	Organization
Monitoring System	Group
Execution System	Group
Actor	Agent
Executive Actor (EA)	Reactive Agent
Monitoring Actor (MA)	Cognitive Agent
Objective	Goal
Indicator	Belief
Action	Plan
Knowledge	Knowledge
Organizational knowledge	Knowledge
Constraint	Knowledge

6. CONCLUSION

In this paper, an agentified metamodel for SMEs supply chain is developed. The methodology that was adopted to obtain this metamodel is also described. The main objective of this work is to capitalize the know-how techniques in order to simplify supply chain modelling and concepts reuse. The perspective of this research work is to study the dynamic behaviour of the agentified metamodel. The final aim of such a research is to implement a simulation platform for supply chain that mostly involves SMEs.

7. REFERENCES

Azaiez S., 2007. Approche Dirigée par les modèles pour le développement de systèmes multi-agents. Thèse de l’Université de Savoie, Spécialité Informatique. December 11, Annecy le vieux, France.

Azaiez S., Habchi G., Huget M.P., Pralus M. and Tounsi J., 2007. Multiagent oriented modelling and simulation for manufacturing systems control. INDIN 2007, 5th IEEE International Conference on Industrial Informatics, July 23-27. Vienna, Austria.

Bagchi S., Buckley S., Ettl M., Lin G., 1998. Experience using the IBM supply chain simulator. Winter Simulation Conference.

Bratman M.E, Israel D.J., Pollack M., 1998. Plans and resource-bounded practical reasoning. *Computational Intelligence*, 4, pp 349-355.

Brooks R.A., Intelligence without representation, *Artificial Intelligence*, 47: 139-160. 1991.

Chopra S. and Meindl P., 2001. Supply Chain Management: strategy planning and operation. Upper Saddle River, NJ: Prentice-hall.

Cooper M., Lambert D.M. and Pagh J.D., 1997. Supply chain management: more than a new name for logistics. *International Journal of Logistics Management*, vol 18, n°2, pp. 1-13.

Demazeau Y., 1996. “Vowels”, Invited lecture, IWDAIMAS96.

Drucker P.F., 1998. Management’s new paradigms. Forbes, October, pp. 152-177.

Fischer K., Müller J.P., Pischel M., 1995. Unifying control in a layered agent architecture. IJCAI95, Agent Theory, Architecture and language workshop, pp 240-252

Julien P.A., 1997. Les PME bilan et perspectives. 2e edition, Economica, Paris, France.

Kent S., 2002. Model-driven Engineering, IFM 2002, vol. 2335 of LNCS, Springer-Verlag, pp. 286-298.

Labarthe O., Espinasse B., Ferrarini A., Montreuil B., 2007. Toward a methodological framework for agent-based modelling and simulation of supply chains in a mass customization context. *Simulation Modelling Practice and Theory*. 15, pp.113-136

Lambert D.M. and Cooper M.C., 2000. Issues in supply chain management. *Industrial Marketing Management*, 29, n° 1, pp. 65-83.

Lee Y.H, Cho M.K., Kim S.J. and Kim Y.B, 2002. Supply chain simulation with discrete continuous combined modelling. *Computer and Industrial Engineering*, 43, pp 375-392.

Longo F. And Mirabelli G., 2008. An advanced supply chain management tool based on modelling and simulation. *Computers & Industrial Engineering*, vol 54, pp. 570-588.

Parunak H., Savit R., Riolo R.L, 1998(a). Agent-based modelling VS equation-based modelling: a case study and user’s guide. Proceedings of Multi-agent systems and agent-based simulation (MABS’98), Springer, LNAI 1534.

Parunak H., 1998. Wat can agents do in industry, and why? An overview of industrially-oriented R&D at CEC. Second international workshop on cooperative information agents, CIA’98, M.Klusch.

Stevens G.C., 1989. Integrating the supply chain. *International Journal of Physical Distribution and Materials Management*, 19, pp 3-8.

Terzi S. and Cavalieri S., 2004. Simulation in the supply chain context: a survey. *Computers in Industry*, 53, pp.3-16.

Thierry C. 2003. Gestion des chaînes logistiques : Modèle et mise en œuvre pour l’aide à la décision à moyen terme. Accreditation to supervise research. University of Toulouse II.

Tounsi J., Boissière J., Habchi G., 2008. A conceptual model for SME Mechatronics supply chain. 6th International Industrial Simulation Conference (ISC’08), Lyon, France, pp. 273-280.

Villarreal Lizarraga, C.L., Dupont L., Gourg D., Pingaud H., 2005. Contributing to management of shared projects in SMEs manufacturing clusters. 18th International Conference on Production Research (ICPR-18), Salerno, Italy.

Wooldridge M., 1999. Intelligent Agents. Multiagents Systems, Weiss G., Ed:MIT Press.

Wooldridge M., 2002. An introduction to Multiagent Systems. Jonh Wiley & Sons, February.